

University of Dundee

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Moseley, H.; Allan, D.; Amatiello, H.; Coleman, A.; du Peloux Menagé, H.; Edwards, C.

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Guidelines on measurement of ultraviolet radiation levels in ultraviolet phototherapy: Report issued by British Association of Dermatologists & British Photodermatology Group 2015

H Moseley, D Allan,* H Amatiello,[†] A Coleman,[‡] H du Peloux Menagé,^{§‡} C Edwards,[¶] LS Exton,[¶] J Ferguson, T Garibaldinos,[‡] C Martin,** MF Mohd Mustapa[¶]

The Photobiology Unit, Ninewells Hospital and Medical School, Dundee, DD1 9SY; *The Christie NHS Foundation Trust and University of Manchester, Manchester Academic Health Science Centre, Wilmslow Road, Manchester, M20 4BX; [†]Radiation Physics and Protection Group, Churchill Hospital, Old Road, Headington, Oxford, OX3 7LJ; [‡]Guy's and St Thomas' NHS Foundation Trust, St Thomas' Hospital, Westminster Bridge Road, London, SE1 7EH; [§]Lewisham & Greenwich NHS Trust, High Street, London, SE13 6LH; [¶]Royal Gwent Hospital, Cardiff Road, Newport, NP20 2UB; [¶] British Association of Dermatologists, Willan House, 4 Fitzroy Square, London W1T 5HQ; **Department of Clinical Physics and Bio-Engineering, University of Glasgow, Glasgow, G12 8QQ

Corresponding author:

Harry Moseley, h.moseley@dundee.ac.uk

HM, DA, HA, AC, HduPM, CE, JF, TG and CM are members of the guideline development group with technical support provided by LSE and MFMM.

Footnote:

This is an updated guideline prepared for the British Association of Dermatologists (BAD) Clinical Standards Unit, which includes the Therapy & Guidelines Sub-committee. Members of the Clinical Standards Unit that have been involved are: PM McHenry [Chairman T&G], M Griffiths, DA Buckley, I Nasr, VJ Swale, CE Duarte Williamson, TA Leslie, E Mallon, K Towers [British National Formulary], C Saunders [British Dermatological Nursing Group], AG Brain [BAD Scientific Administrator], LS Exton [BAD Information Scientist], MF Mohd Mustapa [BAD Clinical Standards Manager].

**These guidelines were first produced by the British Photodermatology Group in 2002
This update was produced jointly by the British Photodermatology Group and the
British Association of Dermatologists in 2015**

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Conflicts of interest:

HM: Runs a UKAS Laboratory calibrating UV meters for phototherapy (specific); AC: Runs a UKAS Laboratory calibrating UV meters for phototherapy (specific); CE: Financial support for departmental educational meetings (specific).

Key words: calibration; dosimetry; guidelines; narrowband UVB; radiometer; spectroradiometer; phototherapy; psoralen ultraviolet A; ultraviolet B; radiation; ultraviolet.



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1.0 PURPOSE AND SCOPE

The overall objective of the guideline is to provide up-to-date, evidence-based recommendations for the dosimetry and calibration of ultraviolet (UV) radiation therapy. The document aims to:

- offer an appraisal of all relevant literature, focusing on any key developments
- address important, practical clinical questions relating to the primary guideline objective, i.e. accurate measurement, equipment variables and human variables
- provide guideline recommendations and, where appropriate, with some health economic implications
- discuss potential developments and future directions

The guideline is presented as a detailed review with highlighted recommendations for practical use in the clinic (see section 18.0, in addition to a Patient Information Leaflet (PIL) on phototherapy available on the BAD website, www.bad.org.uk).

2.0 STAKEHOLDER INVOLVEMENT AND PEER REVIEW

The guideline development group consisted of clinical scientists, consultant dermatologists and a nurse practitioner. The draft document was circulated to the BAD membership, the British Photodermatology Group (BPG) membership, British Dermatological Nursing Group (BDNG), Primary Care Dermatological Society (PCDS), Institute of Physics and Engineering in Medicine (IPEM), Psoriasis Association, Psoriasis and Psoriatic Arthritis Alliance (PAPAA) and a patient for comments, and peer-reviewed by the Clinical Standards Unit of the BAD (made up of the Therapy & Guidelines Sub-committee) prior to publication.

3.0 METHODOLOGY

This set of guidelines has been developed using the British Association of Dermatologists' recommended methodology¹ and with reference to the Appraisal of Guidelines Research and Evaluation (AGREE II) instrument [www.agreetrust.org].² Recommendations were

developed for implementation in the NHS using a process of considered judgment based on the evidence.

Clinical trials are not appropriate for this guideline. The recommendations made are those which are currently considered best practice but will be modified at intervals in the light of new evidence. The structure of the 2002 guidelines³ was discussed and re-evaluated, with headings and sub-headings decided; different co-authors were allocated separate sub-sections. PubMed, MEDLINE and EMBASE databases were searched up to December 2014; search terms and strategies are detailed as a web appendix. Additional relevant references were also isolated from citations in reviewed literature. The results were split into two and working in quartets each set of co-authors screened their set of identified titles/abstracts and those relevant for first-round inclusion were selected for further scrutiny. The authors then reviewed the abstracts for the shortlisted references with reference to their allocated sub-section and the full papers of relevant material were obtained. Each co-author then performed a detailed appraisal of the selected literature, and all drafted sub-sections were subsequently collated and edited to produce the final guideline.

4.0 LIMITATIONS OF THE GUIDELINE

This document has been prepared on behalf of the BAD and is based on the best data available when the document was prepared. It is recognized that under certain conditions it may be necessary to deviate from the guidelines and that the results of future studies may require some of the recommendations herein to be changed. Failure to adhere to these guidelines should not necessarily be considered negligent, nor should adherence to these recommendations constitute a defence against a claim of negligence. Limiting the review to English language references was a pragmatic decision but the authors recognize this may exclude some important information published in other languages.

5.0 PLANS FOR GUIDELINE REVISION

The proposed revision date for this set of recommendations is scheduled for 2020; where necessary, important interim changes will be updated on the BAD website.

6.0 BACKGROUND

The key contribution of the medical physics community to the development of psoralen-ultraviolet A photochemotherapy (PUVA) and UVB phototherapy since its first use in the UK in the 1970s has been to ensure that the dose of UV radiation is administered quantitatively rather than qualitatively.⁴ In 2002 the British Photodermatology Group (BPG) published dosimetry guidelines that codified the experience gained in how best to ensure the phototherapy dose is accurately measured.³ In the decade since, there have been some significant advances in technology for the delivery and measurement of phototherapy dose as well as changes in regulatory and clinical governance environments affecting phototherapy dosimetry.^{5,6} These guidelines take account of the advances and are intended to update and replace those previously published.³

The term 'dose' in the context of clinical phototherapy is taken to be the time integral of the irradiance of the therapeutic radiation over the time during which the skin is exposed.⁷ The irradiance at the skin surface is typically measured in units of power per unit area (e.g. milliwatts per cm² or mW cm⁻²) so that, for an exposure time in seconds, the dose takes on units of energy per unit area (e.g. joules per cm² or J cm⁻²). Confining the definition of dose to that delivered at the skin surface rather than at depth in a volume of tissue, as is common in experimental photobiology, has considerable advantages, not least being its relative ease and reproducibility of measurement.⁷

The early protagonists of UV therapy stressed the importance of careful dosimetry, particularly where patients needed to continue treatment on different irradiation units in the same or different centres^{8,9} and the need to base starting doses on either skin type or the results of phototesting.¹⁰ Similarly, it was recognized that careful detector calibration was needed to measure the output of different irradiation units having different spectral emission characteristics.^{11,12} Despite the early awareness of the need for accurate dosimetry in PUVA, inter-comparisons of UVA dosimetry in the UK found a wide variability in practices and in the accuracy of UVA measurement.¹³⁻¹⁵ Incorrect use of radiometers and poor calibration was found to result in recorded irradiance values that were between 0.5 and 1.5 times the true value.

In a survey of 115 UK UVB-phototherapy centres in 1994,¹⁶ it was noted that the overwhelming majority prescribed UVB by exposure time rather than in radiometric units. This is no longer considered good practice unless there is a calibration factor available to users that allows a conversion to dose, so that the dose, rather than a time, can be recorded in the patient's notes.

The erythema sensitivity of skin changes very rapidly with wavelength in the UVB waveband; at 300 nm the skin is 100 times more sensitive than at 320 nm. Thus, the dose of UVB radiation from a particular lamp necessary to produce a given degree of erythema is markedly dependent on its spectral emission. The need for accurate UVB dosimetry became particularly apparent in the 1990s with the introduction of narrowband UVB (NB-UVB) treatment and the requirement to compare the effectiveness and safety of this new treatment with older broadband UVB (BB-UVB) treatments.¹⁷ The short wavelengths found in BB-UVB are more likely to cause burning than NB-UVB. NB-UVB treatment has now virtually replaced BB-UVB. Guidelines regarding the clinical use of phototherapy have been developed.^{18,19}

The calibration of UV radiometers for phototherapy has also improved markedly in the past decade with the introduction of traceability to national irradiance standards via the National Measurement System (NMS).^{20,21} This makes it possible to ensure that the irradiance measured in one centre is comparable to that measured at other centres using different calibrated radiometers. Evidence of reduced variability in UV radiometer calibrations are seen in inter-comparisons from around Europe published in the 1980s, which showed a spread in measured calibration factors of UVA radiometers of 23%,¹⁴ whilst a more recent study demonstrated only a 6% spread.²² Finally, there have also been valuable instrumental advances with the introduction of compact solid-state spectroradiometers making it much easier than previously to capture spectral information from clinical UVR equipment.^{23,24}

The role of phototherapy has recently been re-evaluated in response to the revolution in biologic therapies for psoriasis.^{25,26} Despite the benefits of these therapies that target specific components of the immune system, it seems clear that phototherapy will remain a cornerstone in the management of psoriasis as well as non-psoriatic skin conditions, because of its acknowledged efficacy, its reasonable financial cost, its compatibility with other therapies and its historically proven utility.

GLOSSARY

Broadband UVB (BB-UVB) therapy	UVB radiation from sources which emit a range of wavelengths between 280 nm and 315 nm used for the treatment of skin diseases.
Cosine response	The UV energy incident on the skin per unit area varies as the cosine of the angle of incidence. UV detectors for measurement of irradiance need to have a similar angular response to reproduce the correct irradiance, and this is referred to as a cosine response.
Cumulative dose	The UV dose accumulated by a patient usually assessed over a complete treatment programme or over all treatments administered during their lifetime.
Designated patient irradiance	UV irradiance at the patient's skin during treatment from a particular phototherapy unit derived from radiometer measurements with appropriate adjustment factors.
Diffuser	Input optic of a radiometer detector commonly consisting of a disk of translucent material designed to collect UVR incident from all directions in order to mimic a cosine angular response.
Diffuse reflectance	The fraction of UVR that is reflected from the skin surface and not absorbed. For skin the reflection occurs in multiple directions and is termed diffuse, unlike a mirror which gives specular reflection in a single direction.
Dose	UVR energy incident on the skin during a treatment or a series of treatments. UVR dose = irradiance × treatment time.
Internal detectors	Internal detectors sited within the UV phototherapy cabin to record irradiance during treatment in real time, provided in many cabins. If calibrated these can be used for setting treatment dose.
Irradiance	Radiant power incident on a surface from all forward angles, per unit area. It is expressed in watts or milliwatts per square centimetre (W m^{-2} or $\text{mW cm}^{-2} \text{nm}^{-1}$) in a specified wavelength range.
Nanometre (nm)	Unit of length, equal to 10^{-9} metre.
Narrowband UVB (NB-UVB) therapy	A narrow waveband of UVR, 311-312 nm emitted by certain fluorescent lamp phosphors (e.g. TL-01 lamps) and found to be more effective than broadband UVB in the treatment of psoriasis
PUVA therapy	Administration of drug Psoralen combined with UVA phototherapy used for treatment of psoriasis and other conditions. The drug, which can be administered orally or topically, sensitizes the skin to UV.

Radiometer	A radiometer comprises a detector and meter for measuring the irradiance of optical radiations. For UV measurement the detector incorporates filters to allow selective measurement of UV irradiance, and these instruments are often referred to as UV meters. Such meters require calibration for each type of source.
Responsivity	The input–output gain of a photodetector, which is measured in terms of the electrical signal per unit optical power or for a radiometer per unit irradiance.
Spectral irradiance	Irradiance defined as a function of wavelength and expressed in watts or milliwatts per square centimetre per nanometre ($\text{W m}^{-2} \text{ nm}^{-1}$ or $\text{mW cm}^{-2} \text{ nm}^{-1}$).
Spectroradiometer	An instrument that measures irradiances of optical radiations per unit wavelength in $\text{W cm}^{-2} \text{ nm}^{-1}$, employed in calibration of sources for UVA or UVB.
UVR	Ultraviolet radiation. UVR belongs to the non-ionizing part of the electromagnetic spectrum and ranges between 100 nm and 400 nm. It is conventionally categorized into three regions UVA, UVB and UVC.
UVA	UVR with wavelengths 315-400 nm. This may be split into two regions UVA1 and UVA2.
UVA1	UVR with wavelengths 340-400 nm.
UVA2	UVR with wavelengths 315-340 nm.
UVB	UVR with wavelengths 280-315 nm.
Wavelength	A fundamental descriptor of electromagnetic radiation, including light. It is the distance between corresponding points of a propagated wave, measured in nanometres.

7.0 CLINICAL REQUIREMENTS

7.1 Accuracy and reproducibility

Accurate and reproducible dosimetry is considered important in phototherapy, not only to ensure that patients can be treated consistently in the same centre or transferred between centres, but also to ensure that a patient's absolute cumulative dose (in J cm^{-2}) can be accurately recorded to aid the management of long-term skin cancer risks.^{27,28}

A dose measurement accuracy of 10% is generally considered adequate for clinical phototherapy.^{29,30} In treatment cabins, for example, patient positioning and the non-uniformity of irradiation of the skin due to its curvature may be more than 15%.¹¹ Similarly, differences in the output of the different lamps in the array can be 15% and fluctuations in the output of lamps during treatment can be as much as 10%.³¹

Modern solid-state UV filter radiometers can make highly reproducible measurements with sequential readings of a stable source varying by less than 1%. However, a meter may

provide a reproducible reading without the reading being accurate in terms of the absolute dose (in J cm⁻²). Indeed, it is difficult in practice to calibrate a field UV meter with an accuracy much better than 10%.^{29,30} The UV meter calibration uncertainties quoted by those UK laboratories operating to the standard ISO17025³² are typically of the order of 10% and are, therefore, adequate for most clinical UV dosimetry. Since the calibration factors provided are specific to radiometers being used with sources having a particular spectral output, the main issue for users is to ensure that they request and use the appropriate calibration factor. Users also need to be aware that UV meter degradation can cause the meter to drift out of calibration, so regular calibration is required.

Although the introduction of traceable dosimetry has been an important step in improving dosimetry accuracy in phototherapy centres, there remain areas of concern, particularly in the variability of dosimetry for NB-UVB phototherapy.²⁹ Large discrepancies in dosimetry between centres seem likely to be due, at least in part, to poor matching of the cosine directional response of UV radiometers^{33,34} and unresolved calibration issues where the spectral output of a source varies rapidly with wavelength.

7.2 Safety

UV radiation is carcinogenic; therefore it is important that exposure of staff and members of the public are within acceptable limits.

Any potential exposure to UVR should be covered by a suitable and sufficient prior risk assessment that is subject to regular review. Any necessary control measures to reduce the risks associated with working with UVR should be documented in this risk assessment and be put in place. Staff should be trained to an appropriate level and be made aware of any control measures that may be required such as the use of personal protective equipment (PPE) or high-factor sunscreen.

Staff should be aware that there may be scattered UV radiation from ceilings or walls around the cabin when working in the general vicinity of cabin and partial-body irradiation equipment. Exposure to these devices and to the environmental scatter is generally low but an assessment of the level of environmental UVR should be carried out in line with the Control of Artificial Optical Radiation at Work Regulations 2010.⁵ Such measurements could be carried out by a local Medical Physics Department or others with the expertise to make such measurements. Measured irradiances should be compared to the legal limits laid down in these regulations, with due consideration made to occupancy and workload factors. There may be additional control measures that are required to reduce environmental UVR such as the use of curtains and drapes.

Recommendations: (*Strength of Recommendation D; Level of Evidence 4*)

- A suitable assessment of risk should include the measurement of environmental UVR levels to which staff are exposed and the identification of appropriate control measures.
- Environmental UVR levels should be within the maximum permissible levels proscribed in the Control of Artificial Optical Radiation at Work Regulations 2010.

7.3 Clinical governance

Delivering safe care is a prime consideration for all healthcare workers. Legal claims can help highlight aspects of practice prone to mishap or dispute. Although dermatology as a whole is a low-risk specialty, phototherapy has been highlighted as a vulnerable area with a significant number of claims resulting from overexposure to UV radiation.³⁵⁻³⁷ The potential long-term risk of skin cancer with cumulative phototherapy treatment is also an important clinical governance consideration.³⁸

Audits of phototherapy provision have revealed great variation in the quality of service provided between centres. The BAD has recently recommended minimum service standards for phototherapy and supporting guidance to inform service.³⁹ These include a phototherapy service review toolkit to provide phototherapy units with a framework for assessing their service against these minimum standards.⁴⁰ Achieving a consistent standard for safe and effective phototherapy service provision across the UK should follow.

8.0 PHOTOTHERAPY EQUIPMENT

Most UV phototherapy treatments are delivered in hospital or clinic settings. Since many patients have large proportions of their skin surface needing treatment, whole-body phototherapy cabins where the patient is surrounded on all sides by banks of UV lamps are the equipment of choice for most treatments. The last few decades have seen an increase in the use of NB-UVB phototherapy, with an accompanying decline in PUVA and BB-UVB treatments.¹⁹ The use of whole-body UVA1 phototherapy has also become more common recently.

For areas with more remote populations without easy access to phototherapy centres, the use of home phototherapy units has proved popular and cost-effective in enabling self-administration of treatment.^{41,42} Whole-body home phototherapy units are more usually an open single bank of lamps, rather than an enclosed whole-body cabin. Any one treatment session therefore consists of four separate exposures: to the front, back, and to the left and right sides.

Partial-body irradiation equipment is also widely used for both self-administered and clinic-based phototherapy. A small bank of lamps in either a flat or curved array is suitable for treating hands, feet or lower limbs. Smaller, hand-held devices are often used for less accessible treatment sites such as the scalp. All such units should be operated in areas where access can be controlled to avoid unnecessary exposure to the beam. In the case of the patient, untreated skin and eyes should be protected as necessary by means of clothes, drapes, goggles or face-shields.

Equipment management issues associated with whole-body treatment cabins are considered in the following sections. Whole-body cabins are typically more sophisticated in operation than partial-body irradiation units, many having in-built automated dosimetry systems. They also present a greater potential hazard because of the higher UV irradiances they generate and the fact that a larger area of the patient's skin is typically irradiated. Many

of the UV dosimetry principles discussed will, however, apply equally to the smaller partial-body units.

8.1 Numbers of fluorescent lamps

Different models of whole-body phototherapy cabin contain differing numbers of lamps; 24, 26, 40 or 48 lamps being the more common. The UV irradiance comprises UVR emitted directly from the lamps and UVR reflected from polished surfaces to the side and rear of the lamps. The angles of these reflectors have a significant influence on the overall cabin efficiency.^{43,44} The reflectivity coefficients of different materials used for the reflectors by the various cabin manufacturers can also vary significantly.⁴³ Increasing the number of lamps within a cabin beyond a certain point does not necessarily increase the irradiance proportionately. A recent study compared outputs from two sets of cabins with similar dimension from the same manufacturer, differing only in the numbers of lamps.^{44,45} Cabins with 24 lamps gave irradiances that were only 11% less than those with 40 lamps. It was concluded that the smaller reflector angle in the 40-lamp cabins reduced the useful output per lamp by a third. The uniformity of illumination, which is the most important factor for treatment delivery, was found to be similar in the cabins with 24 and 40 lamps. Cabins that only employed a simple, flat reflector behind the lamps had lower efficiencies. Irradiances in the range 6 - 8 mW cm⁻² are generally required for NB-UVB therapy, and 10 - 14 mW cm⁻² for UVA therapy. Therefore, cabins with more than 24-30 lamps may offer little advantage in terms of treatment times.

Some cabins have a combination of UVA and UVB fluorescent lamps which operate using separate controllers, to allow treatment with either spectrum. These cabins hold either 16 UVB and 32 UVA lamps or 13 UVB and 27 UVA lamps. Although these cabins save space, the overall cabin irradiance of each modality is proportionally reduced and consequently treatment times are increased. There is also the risk of selecting the wrong treatment mode, although internal dosimetry systems, if these are used, will typically include exposure limits that prevent the longer UVA exposure times being given by the UVB lamps. Therefore this type of cabin is not generally recommended. If it is necessary to have a dual cabin because of space limitations, extreme care must be exercised when entering the lamp type and treatment dose.

The number of lamps in a cabin may affect installation and running costs. Cabins with fewer lamps require less complex electrical supply arrangements, whereas those with 40 or more fluorescent lamps typically require a 3-phase electricity supply that may not be readily available on some sites. They also produce more heat, therefore efficient air conditioning systems are required to maintain patient comfort.

8.2 Exposure control systems

Exposure control in whole-body phototherapy cabins can be either time-mode or dose-mode. Some cabin designs can be operated in only one of these modes, while others offer a choice of either mode of operation. Depending on user preferences, the choice of control modes may be an important consideration when acquiring a new treatment cabin.

Time-mode may be the only control method available on older cabins. The user sets an exposure time corresponding to the prescribed treatment dose, and based on prior irradiance measurements. The cabin's in-built electronic timer then controls the exposure; there is no automatic allowance for differences in patient size, or variations in the cabin irradiance.³¹ To maintain accuracy, a programme of regular irradiance calibration tests is necessary, typically after 50 hours of use and repeated at least every 4 months.

Most currently available cabins are capable of dose-mode control. The cabin is fitted with internal detectors that measure the internal irradiance in real-time during treatment. The operator sets the required dose on the controls and starts the treatment. The control system electronically integrates the continuous irradiance reading, and the exposure is automatically terminated when the set dose is reached. Dose-mode operation can also compensate automatically for fluctuations in irradiance arising both during individual treatments and over a full clinic session. More consistent doses may then result.

The effectiveness and accuracy of in-built sensor systems is dependent on detector position and cabin geometry. Some early designs have been prone to give misleading readings.^{31,46,47} Especially problematic are types reliant on monitoring a small number of lamps.⁴⁸ More recent types compensate reasonably well for differences in the amount of shielding of the fluorescent tubes by patients of differing sizes.^{30,49,50} However, it should be recognized that internal dosimeters monitor the UV that is reflected from a relatively small area of skin and do not measure the average irradiance to the whole patient.

Internal detectors may also be sensitive to the patient's relative position within the cabin. If a patient moves off-centre, the detected cabin irradiance level will alter as the different banks of lamps within the cabin will contribute more or less to the total irradiance. This may cause some variation in the patient's actual received dose, leading to either under- or over-dosing.

It has been shown that cabins fitted with a pair of detectors are less susceptible to this type of dose error than cabins with single detectors.^{31,50}

When in-built, dose-mode sensors are fitted, users should not assume that the dose displayed on the cabin's control panel is correct. A programme of regular calibration checking of any in-built metering system should be in place to ensure accuracy and to guard against malfunctions. To avoid confusion, this should be done even if the cabin is normally operated in time mode.

8.3 Safety features

Should a patient fall against unprotected lamps inside a phototherapy cabin, there is a high risk of laceration. Many older phototherapy cabins either had no protection at all against this, or had relatively open metal grilles. Now, full acrylic guards over the lamps are generally fitted as standard. Users of phototherapy cabins without guards in place were required to consider retrofitting them following the publication of the Medical Device Alert [MDA/2003/006] issued by the Medical Devices Agency (now the Medicines and Healthcare products Regulatory Agency) in 2003 and the associated Scottish Safety Action Notice (SAN) in 2003 (SAN(SC)03/14).^{51,52}

Improved ventilation within cabins has also enhanced safety by increasing patient comfort and making it less likely that they will become faint and stumble in the first place.

Newer cabin designs generally have lower UV leakage, through better-fitting doors and UV-opaque viewing windows. Moreover, most cabin doors are now interlocked so that the exposure will stop immediately if a patient pushes against the door. Interlocked patient-actuated pull-cords fitted in some cabin designs have a similar safety function. It may be acceptable to continue to use older cabins without such safety features provided an assessment is made of their safety in the light of current regulatory requirements and best-practice guidance.

Regular cleaning of cabins is imperative for infection control. Accumulated skin flakes and dust on lamps can also degrade the cabin output and internal dosimetry systems. Thorough cleaning of cabins – the screens are taken out and cleaned, reflectors and lamps are wiped and accumulated dust removed – can increase the output of cabins by up to 20%.⁵³

Although concerns have been raised about the safety of patients with artificial implanted devices, a recent investigation in two phototherapy cubicles demonstrated that the cabinets were safe for patients fitted with electrical implanted devices, such as pacemakers.⁵⁴

8.4 Fluorescent tube replacement

The absolute output declines as lamps age. For Philips type TL-01 100 W fluorescent tubes, this decline is rapid over the first 200 operating hours, dropping to 60% to 70% of the initial intensity, before maintaining a relatively constant output until lamp failure. There is a large variation in operating life depending upon local circumstances: in one study, lamp lifetime was observed to be 470 hours \pm 170 hours (mean \pm one standard deviation).³¹

When lamps fail, 'cold spots', or areas of lower localized irradiance are formed within the overall irradiance distribution, thereby under-dosing an area of the patient. New tubes have higher irradiances and so create 'hot spots' or areas of higher localized irradiance. For cabins of the size supplied by most manufacturers, single-lamp failures give cold spots with 7% to 12% lower irradiances and replacement with a new lamp gives 3% to 6% hot spots. If failed lamps are replaced promptly, localized patient erythema is unlikely. However, in cabins with fewer lamps where each lamp contributes more to the overall irradiance, and in smaller cabins where the contribution to irradiance from individual lamps is more localized, irradiance may be some 30% lower in cold spots from single-lamp failures. This effect is particularly important in dual UVA/NB-UVB cabins as these have fewer lamps of each type, meaning the impact of a failed lamp is greater. An added complication is that failed lamps are more difficult to identify among lamps of the other type that are not illuminated.³¹ A robust system to identify and replace failed lamps is therefore required.

Replacement of lamps should be carried out in accordance with an agreed policy that is known and understood by the end-users. One option is to replace all lamps when treatment times become unacceptably long; an alternative strategy is to replace those lamps showing a low output so that irradiance in the cabin is kept constant e.g. within 10% to 20% of a desired figure.

It is critical that the correct fluorescent tubes are fitted in the cabin to avoid accidental treatment with the wrong UV spectrum. Some suppliers label NB-UVB tubes with blue and red stickers for easy identification, but this helpful practice is not a requirement. This means that there remains a risk of an unlabelled NB-UVB tube being fitted in to a UVA cabin, or vice versa, with potentially serious clinical consequences. Recommendations concerning identification have been made in the 2012 Estates and Facilities Alert ERA/2012/002.⁵⁵

Recommendations: (*Strength of Recommendation D; Level of Evidence 4*)

- Consider uniformity of dose distribution, treatment times, control mode options and installation implications when selecting whole-body cabins.
- Cabins fitted with tubes providing identical spectral output are recommended over cabins that can be switched to operate two (or more) different spectral outputs.
- The use of cabins with dosimetry systems providing a biologically-weighted dose are not recommended.
- Regular measurements using a calibrated UV radiometer should be made in order to assess irradiance to which patients are exposed by phototherapy equipment and to check the accuracy of any dosimetry systems that are incorporated within the equipment.
- An infection control and hygiene policy should be in place to ensure adequate cleaning of equipment and other surfaces in phototherapy areas.
- A lamp replacement policy should be in place to ensure that failed or low output lamps are replaced with lamps of the correct type, and that localized areas of low or high irradiance are avoided.

9.0 UV LAMP TYPES

Most UV sources for phototherapy are low-pressure, mercury vapour fluorescent lamps (Figure 1). See elsewhere for a comprehensive description of optical radiation sources in healthcare.⁵⁶ NB-UVB is provided by Philips TL-01 lamps with peak output at 311 nm or Arimed 311 lamps with a slightly longer wavelength peak at 313 nm. Both of these are within the action spectrum for clearance of psoriasis established by Parrish *et al.*,⁵⁷ but the Arimed 311 has slightly more energy in the lower, more erythemogenic region below 310 nm. Philips supply the same phosphor in 9 watt bi-pin and 36 watt four-pin compact fluorescent tube (CFL) format, and in 20 W (2 ft), 40 W (4 ft), 100 W (6 ft) and the newer 120 W (2 metre) straight-tube format.

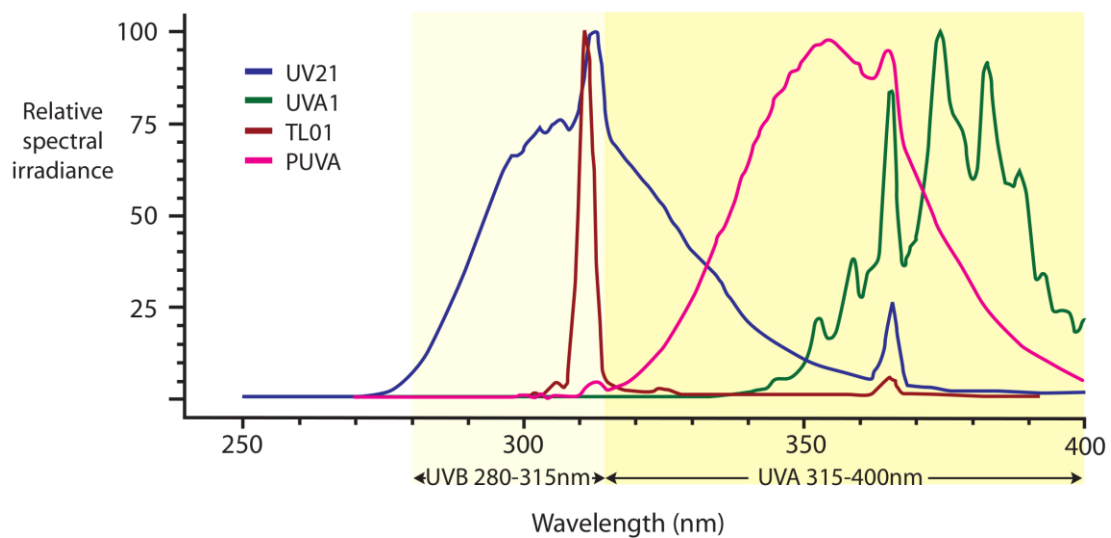


Figure 1. Spectral outputs of typical fluorescent ultraviolet (UV) therapy lamps

BB-UVB lamps emit energies from UVC through to UVA, with peak energy in the UVB. Waldmann UV6 and UV21 and Philips TL-12 emit their main energy between 280 nm and 360 nm with a maximum at 320 nm. They emit wavelengths outside the action spectrum for clearance of psoriasis, so are more erythemogenic than NB-UVB lamps. Their use has declined significantly since the introduction of NB-UVB lamps.

PUVA uses BB-UVA lamps which emit over the whole of the UVA (315 nm to 400 nm, maximum 350 nm). Lamps manufactured by Philips are labelled as tanning products in the Cleo range (often Cleo Performance are supplied for PUVA). There are many Cleo lamps, and recently the “Cleo Natural” lamp has been introduced with a higher UVB content. They are also supplied as ‘PUVA Lamps’, and are available in similar size and wattage options as described for NB-UVB lamps above. Some UVA lamps have an in-built reflector to increase the irradiance; these are designated R-UVA.

There is some evidence for the effectiveness of long-wave UVA-1 (340 nm to 400 nm) for phototherapy. Fluorescent lamps of the Philips TL-10 phosphor are available for populating conventional phototherapy cabins. This is a NB-UVA lamp with emission between 350 nm to 400 nm, peaking at around 370 nm.

Other phototherapy sources include medium-pressure metal halide lamps (iron or cobalt halides are common). These emit broadly across the UV and visible, so are almost exclusively used with filters to shape the output spectrum. They are available in power ratings up to 2 to 3 kW, so are used in UVA-1 phototherapy units with output irradiances in the range of 90 mW cm⁻² to 130 mW cm⁻².

10.0 PATIENT VARIABLES

Skin type and habits affecting routine UV exposure together determine the UV dose that the skin can endure without an adverse reaction. The choice of irradiance level at which treatments can begin is not straightforward as skin responses will vary for different parts of the body. It is further complicated by the fact that the shape and size of each individual influence the irradiance levels at the skin.

The overriding factor determining the dose at which to start a phototherapy treatment is the patient's own UV skin sensitivity. The UV dose required to produce erythema, the minimal erythema dose (MED), varies by a factor of about four in Caucasians.^{58,59} The minimum phototoxic dose (MPD) for PUVA treatment is even more variable due to differences in psoralen pharmacokinetics⁶⁰ and there is a factor of at least ten between individuals.⁶¹ Therefore the appropriate starting dose must be determined for any treatment; this can be done either by skin photo-typing or measurement of the MED or MPD.

Photo-typing is used by two thirds of UK dermatology departments.⁶² Most employ a simple visual assessment based on the Fitzpatrick scale.⁵⁸ However, this is subjective and combines two different types of skin reaction: generation of erythema and the ability to tan.⁵⁸ Some studies show that skin type and MED are correlated, although with significant overlap between types,⁶³⁻⁶⁶ while others report that it is not a good predictor of erythema response.⁶⁷⁻⁶⁹

Many centres measure MED for each patient prior to commencement of treatment to select the starting dose and exclude the possible risk of severe burns. An assessment is then made of the dose for which a trace of erythema is apparent 24 hours later. A similar system is used for measuring the MPD prior to PUVA, but the erythema has a delayed onset, so the assessment is made 72 hours following exposure. Commercial units enable the phototherapist to expose small areas of skin to different UV doses. One type that closes electrically operated shutters at predetermined times can be used with the treatment source. Another has a series of windows covered by grids of differing hole size which attenuate the UV by different amounts, allowing a range of doses to be given with a single treatment time.^{4,62,70,71} If these MED testers are to be useful it is important that they are calibrated to the same UV spectrum as the treatment units. An important requirement for accurate use of these testers is that the aperture through which a patch of skin is irradiated is located in close contact with the skin.

The UV sensitivity of an individual varies between body sites by a factor of about 1.5.⁷² Skin on the trunk is typically more sensitive than that on the limbs⁷³ and is recommended for MED testing. Following a test, the treatment starting dose is typically chosen to be 40% to 70% of the MED or MPD.⁷²

Clearing of psoriasis is faster from the trunk than the lower legs. One reason for this is that the legs tend to have a thicker stratum corneum and higher pigmentation.⁷⁴ But in addition, the intensity towards the base of the cabin is lower, as fluorescent UV outputs fall towards the ends of the lamps in treatment cabins.⁵⁰ Increasing the treatment time for the lower legs by a factor of 1.5 can compensate.

Measurements on manikins show that for a walk-in, whole-body cabin, the majority of the body receives more than 70% of the maximum dose (Figure 2).¹¹ Higher irradiance levels occur at the outer aspects of the arms and shoulders, and those at the lower legs are 25% less.⁵⁰ Sites inclined at an angle to the plane of the lamps, such as the tops of the feet and shoulders, receive lower doses; doses to the sides of the body may be only 50% of the maximum because the area is shielded by the arms. Areas such as the axillae, groin and palms of the hands may receive only about 30% of the maximum.⁷⁵ Although there is a paucity of published data, it is expected that dose to the face is reduced in tall patients.

Phototherapy cabins incorporate reflectors usually made from aluminium to the rear of the lamps to enable as much of the light emitted to be utilized⁴⁴ and these also reflect UV from other parts of the cabin. Thus, when there is a patient in the cabin, the UV irradiance level falls because the patient absorbs some of the UV radiation. Correction factors are applied to allow for this with measurements made by the indirect method, described in 14.2. For NB-UVB, factors between 0.85 and 0.96 have been reported, and for UVA factors between 0.80 and 0.87.^{49,76} The factor may be less for both smaller and elliptical cabins, since the patient intercepts a larger proportion of the UV radiation emitted. For the small Waldmann UV 1000 PUVA cabins, the correction factor is 0.68-0.75.^{46,49} These differences depend on the reflectivity of the aluminium, but large body sizes also reduce the conversion factor by up to 10%.^{49,76}

Recommendation: (*Strength of Recommendation D; Level of Evidence 3*)

- The spectral output of a source used for MED/MPD testing should be identical to that used for the treatment.

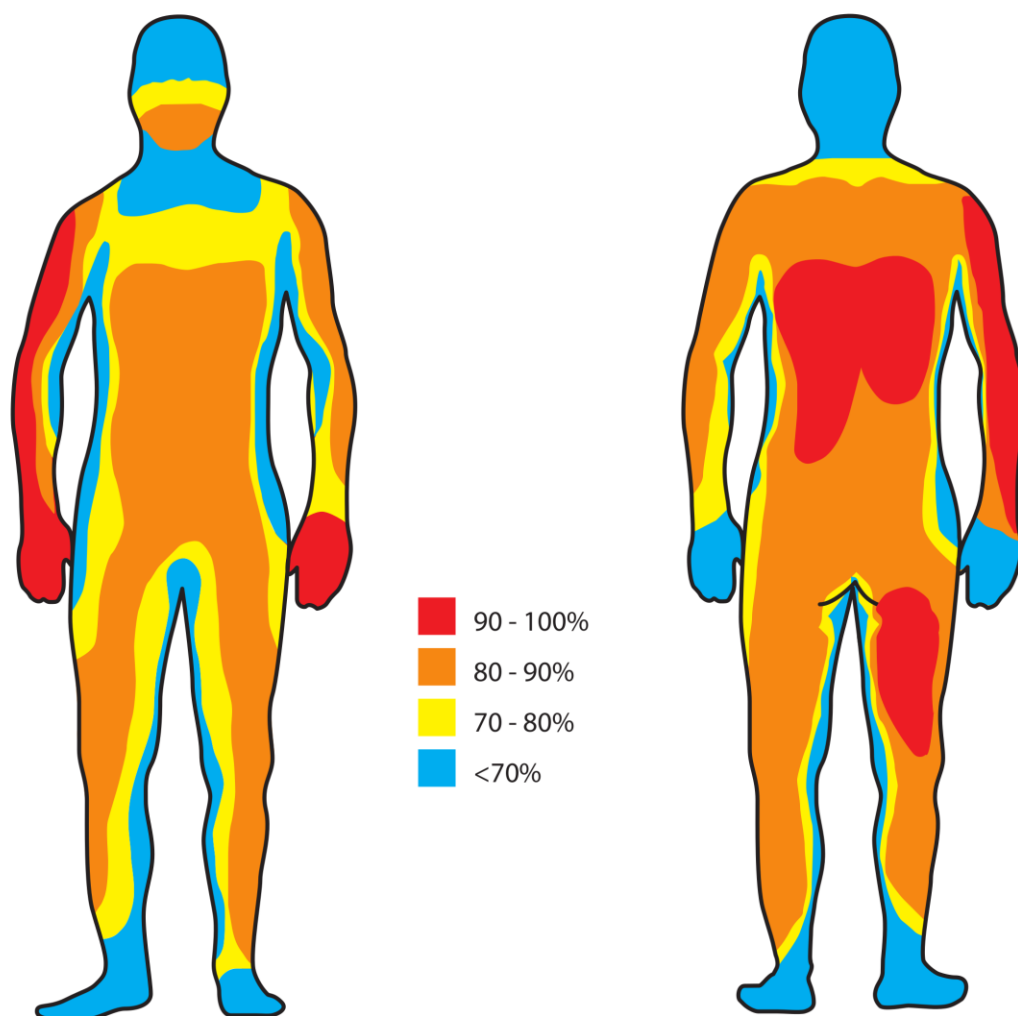


Figure 2. The relative distribution of UV dose on the surface of a manikin resulting from whole-body radiation in a PUVA 6000 unit. Adapted from Diffey *et al.*¹¹ [NB: The difference in UV dose between the two arms is due to higher intensity on one side of the cabin.]

11.0 UV MEASURING EQUIPMENT

11.1 UV radiometers

The importance of using appropriate and suitably calibrated UV radiometers has been repeatedly recognized as critical for the safe and effective delivery of phototherapy treatments.^{3,17,46,77-79} Several descriptions of the features and characteristics of UV radiometers have been published.^{80,81} The key components of a radiometer and its performance attributes can be summarised as follows:

- **UV sensor** – The UV sensor converts incident UV energy into an electrical signal. In many radiometers, the sensor is a silicon (Si) photodiode. Si photodiodes have a

spectral response extending over UV wavelengths, visible light and near-infrared radiation. At shorter UV wavelengths, vacuum photodiode sensors are often employed.^{29,30,82} Gallium arsenide phosphide (GaAsP) photodiodes are also effective UV sensors.⁸³ Thermopile sensors have been used in the past for UV dosimetry work,^{84,85} but are now normally used only in special situations where their distinctively flat spectral response is advantageous.

- **Optical filter and spectral response** – UV sensors have broad spectral responses, so the UV wavelength range to be measured must be separated from any unwanted or out-of-band radiation by an optical filter. With different filters, radiometers based on Si photodiodes can be made to respond primarily either to UVA or UVB wavelengths. Practically achievable spectral responses do not cut off sharply at exact wavelengths, but instead tail off at either end of the range. Several examples of radiometer spectral responses have been published.³⁰

A special example of a filter-modified response is that of a radiometer with a net spectral response mimicking the hazard-weighted action spectrum. This can be achieved with a vacuum photodiode sensor and a matched filter.⁸² Such radiometers can be calibrated to indicate directly hazard-weighted irradiances with acceptable accuracy, irrespective of the exact emission spectra of the UV source. This can aid the assessment of occupational UV exposures.

- **Input optic and angular response** – The input optic of a radiometer is of great importance in UV phototherapy measurements. To correctly measure irradiance, the radiometer response must vary as the cosine of the angle of incidence of UV rays. This is often referred to as the 'cosine response'. Irrespective of type, no UV sensor will give a true cosine response on its own. The closeness or otherwise of a radiometer's angular response to a true cosine response can be described by the f_2 error.^{33,86} The ideal cosine response can be closely approximated by fitting an optical diffuser as the front element of the UV radiometer. Commonly, diffusers are formed of either a Teflon disc or of quartz. The quality of the angular response depends critically on the exact construction and shape of the diffuser.³³ Other examples of radiometer angular responses have been given by Coleman *et al.*³⁰ As a deficient angular response can cause substantial errors in some UV irradiance measurements, especially those within whole-body phototherapy cabins, this aspect of radiometer performance has been investigated in detail.^{33,34,87} It has been concluded that an f_2 error of 10% or less is necessary for good accuracy in calibrating whole-body cabins,⁴⁶ and that reducing the f_2 error to 5% or less is desirable.^{3,33}
- **Dynamic range** – Dynamic range is the span between the lowest and highest UV intensities to which a radiometer responds correctly. A range of 0.05 mW cm⁻² to 50 mW cm⁻² is likely to be adequate for normal phototherapy work.³
- **Linearity** – If a radiometer has a linear response, it will indicate fractional changes in UV irradiance correctly, irrespective of the general irradiance level. The wider the dynamic range, the more important is ensuring accurate linearity of response throughout that range. For routine phototherapy work, a deviation of less than 2% from true linearity has

been recommended.³ Safety measurements around UV phototherapy equipment are particularly demanding of dynamic range and linearity,⁸⁸ but higher-quality radiometers are likely to offer sufficient performance.⁸²

- **Resolution** – Within the electronic circuitry of the radiometer, any internal analogue-to-digital convertor and the meter display must have sufficient resolution to indicate the measured UV irradiance to adequate numerical precision for the purpose. Typically, a digital readout with a display resolution of $\pm 0.1 \text{ mW cm}^{-2}$ is adequate for most clinical phototherapy applications.

The foregoing considerations result in UV radiometers coming in many formats and with differing levels of performance. Several examples are shown in Figure 3. One size does not fit all; the imperative is to match the radiometer's capabilities to the measurement task, taking into account such factors as the spectrum to be measured, irradiance levels, and whether the measurement is a relative check of constancy of an absolute calibration.



Figure 3. Examples of UV radiometers.

11.2 Spectroradiometers

Spectroradiometers separate electromagnetic radiation into its component wavelengths and measure spectral irradiance within each waveband. The measured radiation is expressed in radiometric units such as $\text{mW cm}^{-2} \text{nm}^{-1}$. There are two types of spectroradiometer, the scanning spectroradiometer (SSR) and the charge coupled detector (CCD) array. SSRs have more sensitivity than CCD arrays but are slower and less suitable for field-based measurements. CCD arrays are used where simultaneous, almost real-time updating of the whole spectra is required, although some CCDs suffer from high levels of stray light. CCD spectroradiometers utilising 2-D arrays can be used as imaging spectroradiometers. Spectroradiometers may be calibrated by exposure to a well characterized source of light with known spectral irradiance. The National Physical Laboratory in the UK provides calibrations of such reference sources. Such sources need to be highly stable. Typically, deuterium and/or tungsten lamps are used with stabilized power supplies.

CCD arrays are relatively cheap and are easy to use in the field. However, they must be used with the same level of care in terms of calibration and conditions of use as apply to the traditional SSRs. They are prone to high levels of stray light which can introduce significant errors and they also require to be calibrated to compensate for quantum efficiency.

11.2.1 SSR

- **Input optics** gather radiation from a specific field; for phototherapy lamp measurements a cosine diffuser on the input is required if the spectroradiometer is to provide irradiance at a surface such as presented by the skin.
- The **monochromator** consists of a diffraction grating of finely etched or holographically printed parallel lines which produce a wavelength-dependent angular dispersion of light. Light enters through an input slit and is directed on to the diffraction grating via collimating optics. The grating is rotated to scan the separated spectrum across an exit slit which delivers a small range of wavelengths to the detector. The exit slit (usually the same width as the input slit) then defines the range of wavelengths of light (typically a few nanometres) emerging from the monochromator. Since stray light can introduce significant measurement errors in phototherapy applications, double-monochromator spectroradiometers are typically recommended where accurate measurements are required. Stray-light rejection factors (the ratio of stray-to-incident light) of up to 10^{-6} are achievable with double monochromator systems; some 1000 times better than single monochromator designs.
- The **detector** measures the intensity of radiation within each wavelength range: commonly used detectors are photodiodes or photomultiplier tubes (PMTs).

11.2.2 CCD Array

- **Input optics** usually comprise an optical fibre with a diffuser at the distal end. However, for accurate measurements from phototherapy lamps, a cosine-corrected diffuser is essential.
- The **monochromator** is a compact static grating.
- The **detector** is a CCD array (single-line or a 2-D array) which measures the whole or a large part of the spectrum reflected from the grating. This allows capture of the whole

spectrum simultaneously. Wavelength resolution is determined by the number, size and separation of the CCD elements, the grating characteristics and the optical geometry.

More information on spectroradiometry can be found here.^{80,89,90}

Recommendations: (*Strength of Recommendation D; Level of Evidence 4*)

- A spectroradiometer used to calibrate phototherapy sources should itself be traceably calibrated to a primary reference standard at regular intervals.
- A double-grating design is recommended to ensure adequate rejection of stray light by the spectroradiometer.

12.0 UV RADIOMETER CALIBRATION CERTIFICATES

One of the significant advances in dosimetry for UK phototherapy over the past decade has been the introduction of traceability in UV radiometer calibrations. It is now considered good practice for phototherapy centres to retain documentary evidence of traceable UV radiometer calibrations. Such evidence, typically in the form of a calibration certificate, should contain at least details of the provenance of the calibration, the date it was carried out, the calibration factor for the identified radiometer and a statement of the uncertainty of the calibration. It is important to calibrate the radiometer to the correct source, i.e. the lamp spectrum that it will be used to measure. Although frequency of calibration is somewhat arbitrary, it is generally accepted that recalibration should be carried out annually. These certificates represent a phototherapy centre's evidence that they are managing the UV dosimetry in a manner that provides consistency with other centres. The term "measurement traceability" is used to refer to an unbroken chain of comparisons relating an instrument's measurements to a known standard. In the UK, traceability can be obtained under the National Measurement System (NMS). The NMS promotes an infrastructure of calibration laboratories that can demonstrate traceability of measurement to primary scales at a National Measurement Institute (NMI) via ISO17025 compliance. These laboratories are currently audited and accredited by the United Kingdom Accreditation Service (UKAS). It is good practice to use an accredited laboratory to undertake radiometer calibration.

The National Physical Laboratory is the UK's NMI and realises the national scales and standards for UV radiation from which UKAS accredited laboratories themselves ultimately acquire their traceability. NMIs in other countries include the National Institute of Standards and Technology (NIST, USA), the Laboratoire National d'Essais (LNE, France) and the Physikalisch-Technische Bundesanstalt (PTB, Germany). An inter-comparison of spectral irradiance measurements by 12 NMIs in 1991 found the standard deviation was about 2% in the UV region, demonstrating the high level of measurement accuracy and consistency these laboratories can achieve.⁹¹

Recommendation: (*Strength of Recommendation D; Level of Evidence 4*)

- Phototherapy centres should retain certificates to demonstrate traceability of calibrations for any UV radiometers used in patient dosimetry.

- Recalibration of the radiometer should be performed regularly. It is good practice to do this annually.

13.0 METER CALIBRATION METHODOLOGY

Performing accurate and traceable calibration of UV radiometers for phototherapy applications is difficult and is most appropriately provided by specialist laboratories that can provide users with documentary evidence of traceability to national standards by, for example, accreditation to ISO17025, the globally recognized standard developed specifically for testing and calibration laboratories. Such laboratories can provide calibrations either by comparison with measurements of a BB-UV source made with a traceably calibrated spectroradiometer, or by comparison with measurements made in a monochromatic beam with a traceably calibrated radiometer. These two approaches are both valid and require access to calibrations made at a national measurements laboratory.

A UV radiometer calibration must not only be accurate but must be appropriate for the particular application in which the radiometer is used. Some manufacturers provide new radiometers with a calibration at a single wavelength, typically 365 nm for a UVA radiometer. This may be adequate for many industrial uses but for most phototherapy applications an appropriate BB-UV calibration is required. All UV radiometers must, therefore, be individually calibrated for every type of UV source to be measured, typically UVA, NB-UVB and BB-UVB. Similarly, UVA-1 treatments can be provided by mercury discharge, metal halide lamps or also fluorescent tubes. These can have significantly different spectral outputs and a radiometer calibration factor is needed for each type of source. The ISO17025 standard requires that the calibration provided must be appropriate for its intended use. This standard, therefore, provides users with some assurance that the calibration is appropriate for the specified phototherapy application. The following sections describe how BB-UV calibrations are made.

13.1 Calibration using a calibrated spectroradiometer

In this method, a lamp which has been calibrated at the NPL functions as the transfer standard.⁹² It is set at a defined distance from a spectroradiometer (which should be a double-grating device) in an accurate and reproducible manner, such that it replicates the distance and orientation at the NPL when the calibration was carried out. The calibration laboratory should have at least one other similar lamp and a second lamp of a different type, e.g. a tungsten filament lamp and a deuterium lamp, to allow for internal quality control checks to be performed. The spectroradiometer should be calibrated either each time it is used or on a regular basis (e.g. annually) with checks carried out in between. The calibrated spectroradiometer may then be used to calibrate the UV detector against specific lamps, e.g. PUVA and TL-01 in the following way:

- measure the spectral irradiance from the desired lamp using the calibrated spectroradiometer
- integrate the spectral irradiances across the waveband of interest
- substitute the UV detector in place of the spectroradiometer and note the reading

- adjust the meter display or provide a correction factor to give agreement with the integrated spectroradiometer value

Because UV detectors do not have a uniform wavelength sensitivity, calibration must be repeated for each different type of lamp.

13.2 Calibration using a calibrated radiometer

This method uses a calibrated reference detector as the transfer standard.²¹ The responsivity of the test detector at a particular wavelength in a normally incident beam is measured. It is determined by inter-comparison with the calibrated reference detector in light generated by a Xe(Hg) arc lamp which passes through a condenser lens, filter and monochromator system. The absolute spectral responsivity of the test detector is determined at a single wavelength and the relative spectral responsivity at other wavelengths is obtained. Angular response of the detector is then measured and an angular correction factor applied to take into account the angular distribution of radiance in a whole-body treatment cabin. The measured meter characteristics are then used along with tabulated data on the spectral properties of the source, obtained using a spectroradiometer.

Uncertainty of the reference detector is slightly less than that of the calibration lamp but the final overall uncertainty of the UV detector calibrated by either method is very similar. Inter-comparisons between two accredited laboratories following ISO17025, one using a lamp-based calibration and the other detector-based, show good agreement (within 4%).⁹³

Recommendations: (*Strength of Recommendation D; Level of Evidence 4*)

- UV radiometers used for dosimetry in phototherapy should be calibrated annually with a calibration traceable to a national standard.
- Users should ensure that calibrations are obtained from calibration laboratories that have a robust methodology in place so that the UV radiometer calibration is accurate, reproducible and appropriate for the application.

14.0 WHOLE-BODY CABIN MEASUREMENTS

The dose the patient receives during their UVR exposures should be as close to the prescribed dose as possible. There are a number of methodologies to help achieve this but all involve competent calibration of the phototherapy units. Light output and performance of the fluorescent lamps are affected by the temperature of the lamp wall. For this reason, the lamps should be switched on for a sufficient time (usually around 5 minutes) to allow the output to stabilise before making measurements.⁹⁴ It is well understood that the final radiation incident upon the patient's skin is from both direct irradiance from the lamps themselves and from reflected radiation from the reflectors. The patient's skin absorbs some of the incident radiation and also reflects some back into the cabin. The calibration method employed should make allowance for this patient effect on the final irradiance. There are two commonly used approaches to achieve this: the direct and the indirect method.⁴⁶

14.1 Direct method

In this approach the patient effects on the cabin irradiance are accounted for by physically entering the cabin (whilst fully protected from the UV) and holding the radiometer close to the body to measure, as realistically as possible, the irradiance at the position of the skin. While the cabin is switched on, the assessor takes 12 body site measurements: four at chest level (anteriorly, posteriorly and on their left and right sides), four at waist level and four at knee level (Figure 4). The mean of these 12 irradiance measurements, the Designated Patient Irradiance (DPI), is then taken as the irradiance used to determine treatment times for UV dose delivery, and inherently accounts for the effect on the irradiance of the presence of the patient in the cabin. Some centres measure around the body at mid-tube height only in order to capture the highest irradiance values but this overestimates the average dose to the body. Any potential problems caused by using the DPI are easily rectified by using a slightly lower treatment dose. The advantage of DPI is that it is a standardized methodology that facilitates inter-comparison between treatment centres.

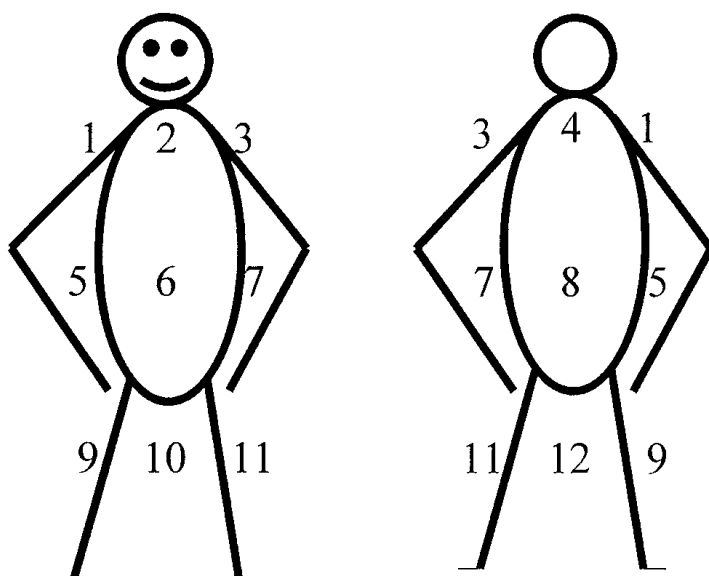


Figure 4. Diagram showing the body sites used to determine the Designated Patient Irradiance.

As an assessor is physically entering a cabin there is an obvious requirement for them to wear the necessary PPE and ensure that all exposed skin (including areas that may be overlooked such as the top of the head or the back of the neck) and the eyes are adequately protected. Generally, the use of overalls and gloves are employed, supplemented by the use of a high-factor sunscreen on skin that cannot be covered. Eyes and the face should be protected with the use of a visor. It should be noted that some protective clothing may be more reflective than human skin.^{79,95}

14.2 Indirect method

This method does not involve a person entering the cabin to perform the calibrations which gives an obvious safety advantage. Instead, the radiometer is set up in an empty cabin, at mid-height on a tripod or similar support. The irradiance of each bank of detectors is

measured in turn. A device for automating the measurements by scanning a radiometer probe around a 360° circle 30 cm in diameter at waist height has been described.⁹⁶

The mean irradiance measured in this way will generally be higher than that actually incident on the patient's skin since there will be no patient shielding of the radiometer. It cannot, therefore, be used as the DPI. In this case, the mean irradiance must be corrected for patient effects by multiplying by an occupancy correction factor (the ratio of the irradiances measured in the occupied and unoccupied cabin). Occupancy correction factors are tabulated for the more common cabin designs, obviating the need for their measurement in most cases.^{46,49,76,97} However, since the occupancy correction factor can depend somewhat on the combination of the cabin design and the angular response of the radiometer, there is merit in checking the factor for each combination of cabin type and radiometer in use at each centre.

14.3 Application of irradiance readings

Having obtained a DPI directly or indirectly, it is relevant to discuss how this value should be used. This will depend on the clinical mode of operation of the cabin.

- a) **Time-controlled mode:** Where cabins are operated in time-control mode, the DPI value is used to calculate the treatment time to deliver the prescribed dose.

$$\text{Dose (mJ cm}^{-2}\text{)} = \text{DPI (mW cm}^{-2}\text{)} \times \text{time (seconds)}.$$

Likewise, for equipment such as the Waldmann UV1000L, where the cabin controller nominally operates in a dose-control mode but where the exposure time is actually calculated internally by the controller from a stored irradiance value, it is the patient irradiance figure which must be programmed into the cabin controller.

- b) **Manual dose-control mode:** Some other cabins, such as the Waldmann UV5001 series units, operate in a manual dose control mode. The operator enters a dose in J cm⁻², which is automatically converted to an exposure time based on a stored irradiance value. This stored irradiance value is periodically refreshed by an internal self-test. In this case, the measured DPI should be compared with the stored irradiance value to determine whether the cabin calibration based on the self-test is satisfactory. Agreement should be within 10%.
- c) **Automated dose-control mode:** For cabins fitted with a continuously-integrating internal irradiance metering system and operated in dose-control mode, the DPI should be compared directly with the irradiance value from the cabin's internal metering system. Verifying that the internal detector system compensates appropriately for patient occupancy requires some form of direct-method measurement.⁵⁰ Again, the cabin dosimetry system should provide an irradiance that is within 10% of the DPI obtained using either the direct or indirect method.

Recommendations: (Strength of Recommendation D; Level of Evidence 4)

- The DPI in all treatment cabins should be regularly measured, by a direct or indirect method using a traceably calibrated radiometer.
- All irradiance values used in the calculation of patient dose should be within 10% of the measured DPI.

15.0 ORGANISATIONAL AND FINANCIAL IMPLICATIONS

Any organisation providing phototherapy or photochemotherapy must have a system in place to ensure that any patient undergoing treatment receives the prescribed dose to an acceptable level of accuracy. To this end, there must be a person with suitable expertise in medical physics appointed who has the knowledge and experience to oversee the dosimetry programme. This person will have the responsibility for the UV measurement programme whether it is carried out in-house or outsourced. The responsible person should ensure that measurements are performed in a suitable manner, at the required frequency, and using appropriate and calibrated equipment. This is equally applicable to units that use internal detectors, as their calibration must also be monitored.

16.0 FUTURE DIRECTIONS

NB-UVB treatment represents an important and relatively new therapy for psoriasis.⁹⁸ It has largely replaced both BB-UVB and PUVA as initial choice in full-body phototherapy in many units.⁹⁹ However, dosimetry in clinical NB-UVB [311 nm] therapy remains a problematic area. An inter-comparison of the calibrations provided by seven medical physics departments for the same radiometer showed that the ratio between the maximum and minimum calibration factors was 2.74 for NB-UVB.²⁹ It is clearly important that treatment centres should all be using radiometers with calibrations performed by laboratories offering assured traceability. Clearly, continued data gathering and evaluation is needed to provide assurance that NB-UVB therapy doses are consistent across the UK and that sources of uncertainty that apply particularly to NB-UVB dosimetry are fully understood.

Single monochromator detector CCD array spectroradiometers have become widely available over the past decade and are valued as field instruments being easily portable and relatively cheap compared with mechanical double-grating spectroradiometers.¹⁰⁰ They are also fast, providing a spectral measurement in less than a second compared with several minutes using a mechanical double-grating instrument. This enhanced speed of spectral acquisition opens up the possibility of new applications in UV dosimetry for phototherapy, as well as time-resolved spectral measurements in research applications. The use of array spectroradiometers for clinical UV dosimetry, however, is not yet feasible due to large errors that can arise from their relatively poor stray-light rejection performance.²⁴ For this reason these devices are currently used in phototherapy applications requiring only relative rather than absolute spectral measurements in clinical applications, such as assessing lamp spectra. There have been efforts to reduce stray-light errors in these instruments,²³ and manufacturers have started to implement such improvements with phototherapy applications in mind. Continued careful evaluation of new instrumentation will be required before these devices can be safely introduced to replace radiometers for clinical UV dosimetry.

Of the recent innovations in cabin design, perhaps the most significant for UV dosimetry over the past decade has been the introduction of in-built metering systems that are intended to provide fully automated dosimetry. The medical physics community in the UK has been generally sceptical about the accuracy of some of these systems from experience in comparing the readings they provide with those from hand-held calibrated radiometers used inside the cabins, but there is little comprehensive published evidence relating to the accuracy of different systems although there is some evidence that dual detector systems can be accurate.³¹ This is an area where more research is needed. By supporting the improvement and development of this technological innovation in dosimetry through careful evaluation of the practical issues in the clinic with such systems, it should be possible to ensure that this technology is introduced in the safest and most effective way for the benefit of phototherapy services.

17.0 RECOMMENDED AUDIT POINTS

Over the past 12 months was there:

1. A log of cabin maintenance?
2. A regular log for UV irradiance measurements for all treatment equipment and that the values are within accepted ranges?
3. A log of radiometer calibration for each type of UV source, identifying the method, its traceability to known national standards and the waveband over which irradiance is measured?
4. A log of dosimeter comparisons between built-in UV dosimeters and directly measured irradiance values, and that the values are within reasonable tolerance ($\pm 10\%$)?
5. A log of an electrical safety standards compliance test?
6. A review of UV exposure risk assessment?

18.0 SUMMARY

(See full manuscript for details of evidence)

As indicated in the background section, undertaking clinical trials are not appropriate in this context. As the current system used for grading the strength of recommendations is directly related to the type of study, all recommendations made in this guideline can only be given a ***Strength of Recommendation D***.

Safety	A suitable assessment of risk should include the measurement of environmental UVR levels to which staff are exposed and the identification of appropriate control measures.
	Environmental UVR levels should be within the maximum permissible levels proscribed in the Control of Artificial Optical Radiation at Work Regulations 2010.
Phototherapy	Consider uniformity of dose distribution, treatment times, control mode

equipment	options and installation implications when selecting whole-body cabins.
	Cabins fitted with tubes providing identical spectral output are recommended over cabins that can be switched to operate two (or more) different spectral outputs.
	The use of cabins with dosimetry systems providing a biologically-weighted dose are not recommended.
	Regular measurements using a calibrated UV radiometer should be made in order to assess irradiance to which patients are exposed by phototherapy equipment and to check the accuracy of any dosimetry systems that are incorporated within the equipment.
	An infection control and hygiene policy should be in place to ensure adequate cleaning of equipment and other surfaces in the phototherapy areas.
	A lamp replacement policy should be in place to ensure that failed or low output lamps are replaced with lamps of the correct type, and that localised areas of low or high irradiance are avoided.
Patient variables	The spectral output of a source used for minimal erythema dose (MED)/minimum phototoxic dose (MPD) testing should be identical to that used for the treatment.
UV calibration equipment	A spectroradiometer used to calibrate phototherapy sources should itself be traceably calibrated to a primary reference standard at regular intervals.
	A double-grating design is recommended to ensure adequate rejection of stray light by the spectroradiometer.
UV radiometer calibration certificates	Phototherapy centres should retain certificates to demonstrate traceability of calibrations for any UV radiometers used in patient dosimetry.
	Recalibration of the radiometer should be performed regularly. It is good practice to do this annually.
Meter calibration methodology	UV radiometers used for dosimetry in phototherapy should be calibrated annually with a calibration traceable to a national standard.
	Users should ensure that calibrations are obtained from calibration laboratories that have a robust methodology in place so that the UV radiometer calibration is accurate, reproducible and appropriate for the application.
Whole-body cabin measurements	The Designated Patient Irradiance (DPI) in all treatment cabins should be regularly measured, by a direct or indirect method using a traceably calibrated radiometer.
	All irradiance values used in the calculation of patient dose should be within 10% of the measured Designated Patient Irradiance (DPI).

SUPPORTING INFORMATION

Addition supporting information, including the search strategy may be found in the online version of this article.

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APPENDIX 1

Levels of evidence

Level of evidence	Type of evidence
1++	High-quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias
1+	Well-conducted meta-analyses, systematic reviews of RCTs, or RCTs with a low risk of bias
1-	Meta-analyses, systematic reviews of RCTs, or RCTs with a high risk of bias*
2++	High-quality systematic reviews of case-control or cohort studies High-quality case-control or cohort studies with a very low risk of confounding, bias or chance and a high probability that the relationship is causal
2+	Well-conducted case-control or cohort studies with a low risk of confounding, bias or chance and a moderate probability that the relationship is causal
2-	Case-control or cohort studies with a high risk of confounding, bias or chance and a significant risk that the relationship is not causal*
3	Non-analytical studies (for example, case reports, case series)
4	Expert opinion, formal consensus

*Studies with a level of evidence '-' should not be used as a basis for making a recommendation.

Strength of recommendation

Class	Evidence
A	<ul style="list-style-type: none">At least one meta-analysis, systematic review, or RCT rated as 1++, and directly applicable to the target population, orA systematic review of RCTs or a body of evidence consisting principally of studies rated as 1+, directly applicable to the target population and demonstrating overall consistency of resultsEvidence drawn from a NICE technology appraisal
B	<ul style="list-style-type: none">A body of evidence including studies rated as 2++, directly applicable to the target population and demonstrating overall consistency of results, orExtrapolated evidence from studies rated as 1++ or 1+
C	<ul style="list-style-type: none">A body of evidence including studies rated as 2+, directly applicable to

	<p>the target population and demonstrating overall consistency of results, or</p> <ul style="list-style-type: none"> • Extrapolated evidence from studies rated as 2++
D	<ul style="list-style-type: none"> • Evidence level 3 or 4, or • Extrapolated evidence from studies rated as 2+, or • Formal consensus
D (GPP)	<ul style="list-style-type: none"> • A good practice point (GPP) is a recommendation for best practice based on the experience of the guideline development group

RCT: randomized controlled trial; NICE: National Institute for Health and Clinical Excellence.

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